Search for heavy metastable particles decaying to jet pairs in $p\bar{p}$ collisions at $\sqrt{s}$=1.96 TeV

Paper Seminar

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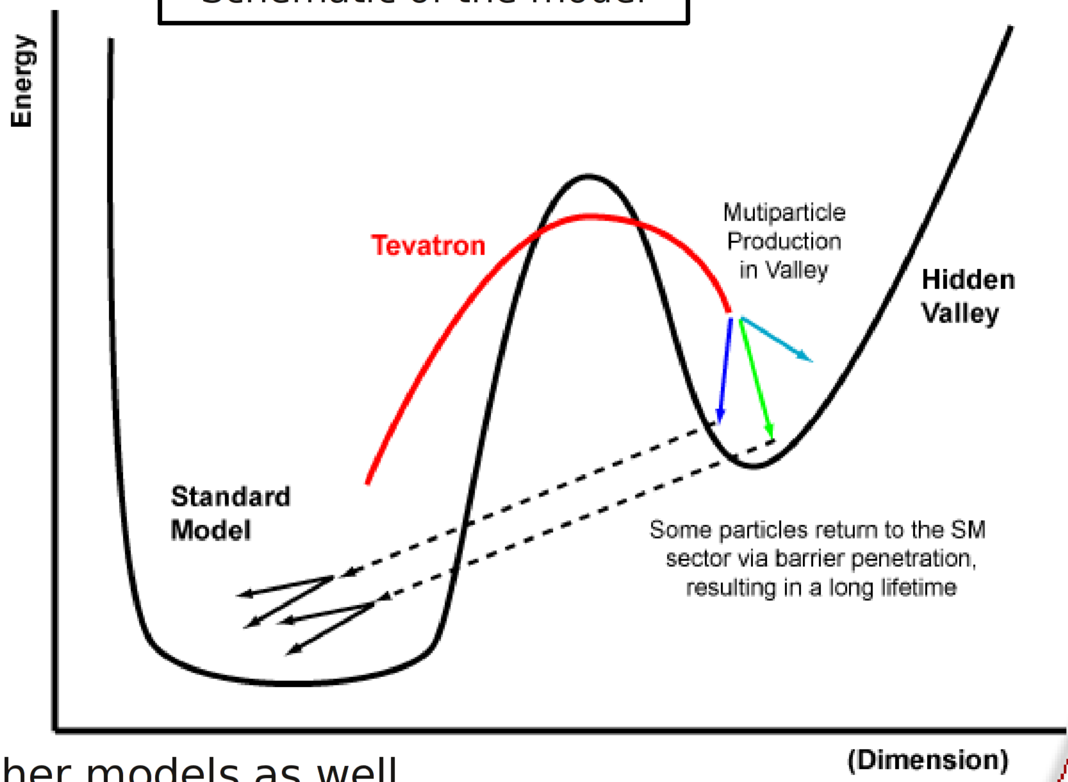
Hidden Valley

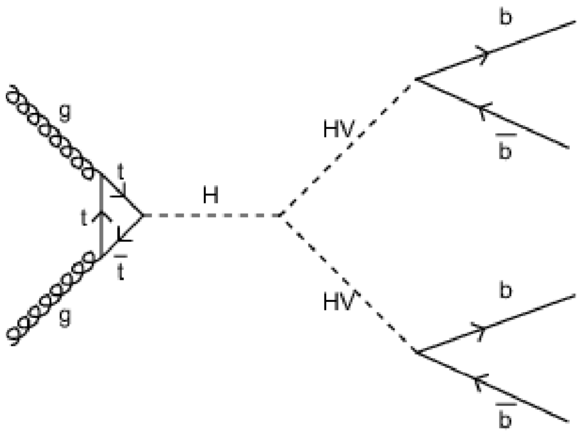
- Energy from collisions enter into the new sector.
- It is transformed into multiple particles through the dynamics of the new sector.
  - These valley-particles (or v-particles) behave in the same way as SM particles.
  - They obey a “v-QCD,”
  - Most likely decay is a v-π.
- Some of these particles decay back into SM particles.
- This model can co-exist with other models as well.
  - SUSY, technicolor, etc.
- It may help in the search for the Higgs.
  - The Higgs may decays into long-lived neutral v-particles, which are heavy and meta-stable. They would decay at a displaced vertex.
  - These would then decay into the heaviest SM fermion available (b-quarks).
- Because this sector is dark, there may be Dark Matter/Astrophysics connections as well.
- In some models (see Kaplan, Luty, Zurek) $c\tau$ for the heavy metastable particle could be of order 1 cm.

Schematic of the model



Title here

- Right:Feynman diagram of HV production
- Below: Outline of the analysis



Generate Signal MC and identify discriminants
↓
Port SecVtx to Stntuple - TStnSVF
↓
Calculate b-tag probability for ZBB Trigger data
↓
Determine flavor fractions of ZBB Trigger data

Identify different data sources for different quark flavors
↓
Create p.d.f. from multiple data sources for difference flavors

↓
Create the Background Estimate using the p.d.f.s of secondary verticies
↓
Optimize Cuts and Perform Counting Experiment
↓
Systematic Uncertainties & Calculate Limit

Model Diagram

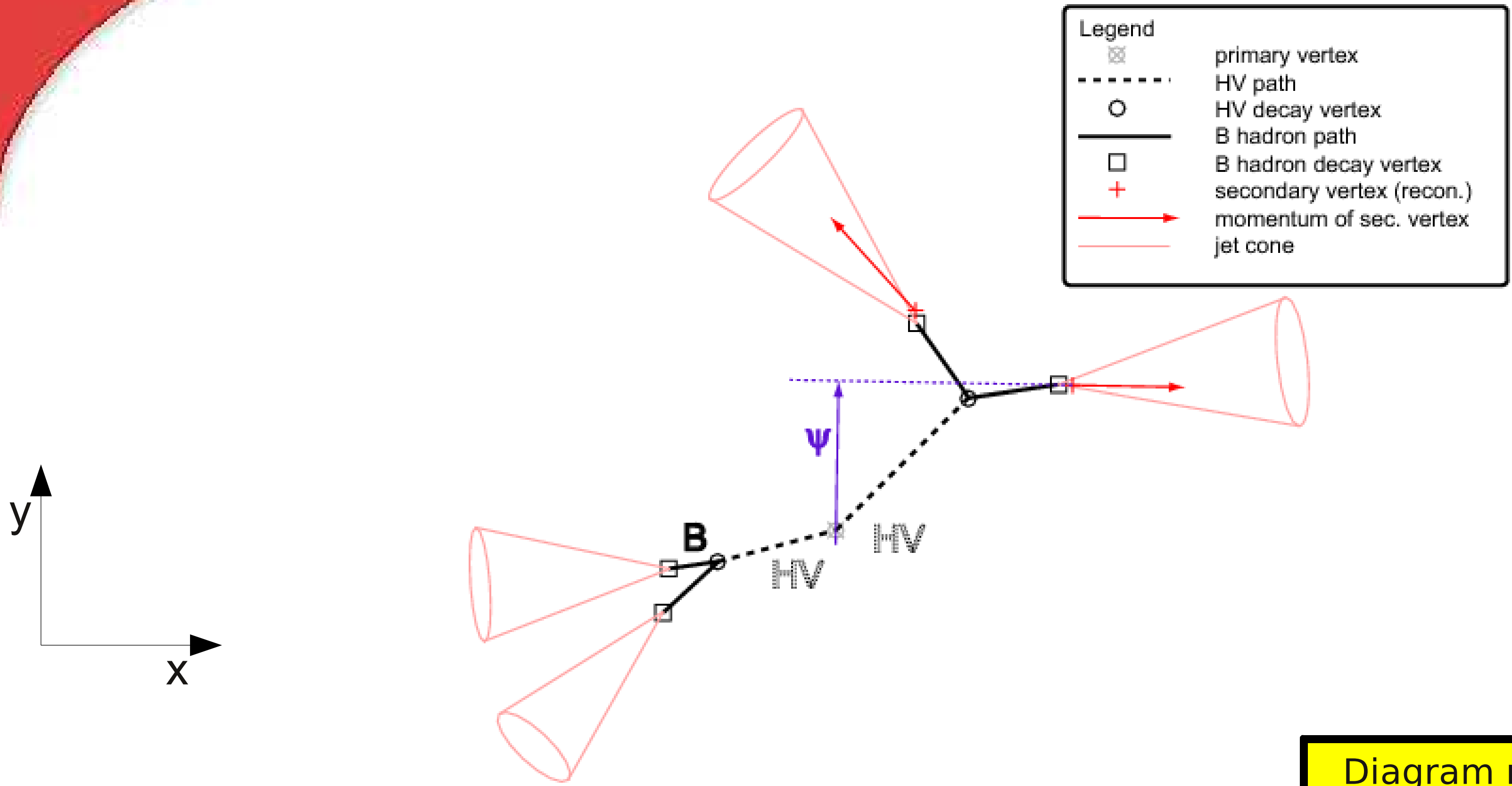


Diagram not to Scale

ψ is the impact parameter of a jet with a secondary vertex.

This is in two-dimensional space.

Model Diagram

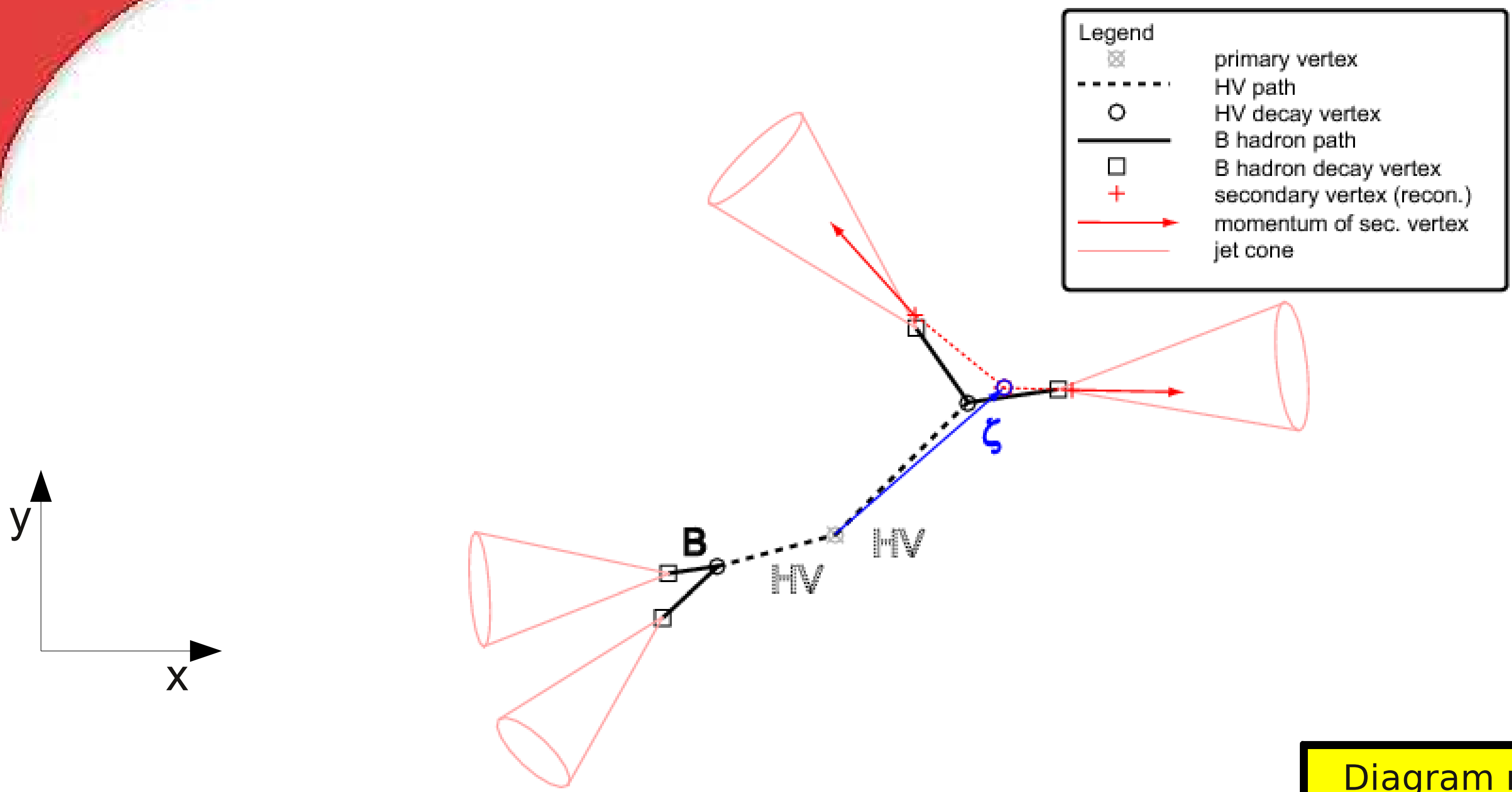


Diagram not to Scale

ζ is the reconstructed decay distance of the HV particle. It requires two tagged jets.

This is in two-dimensional space.

Model Diagram

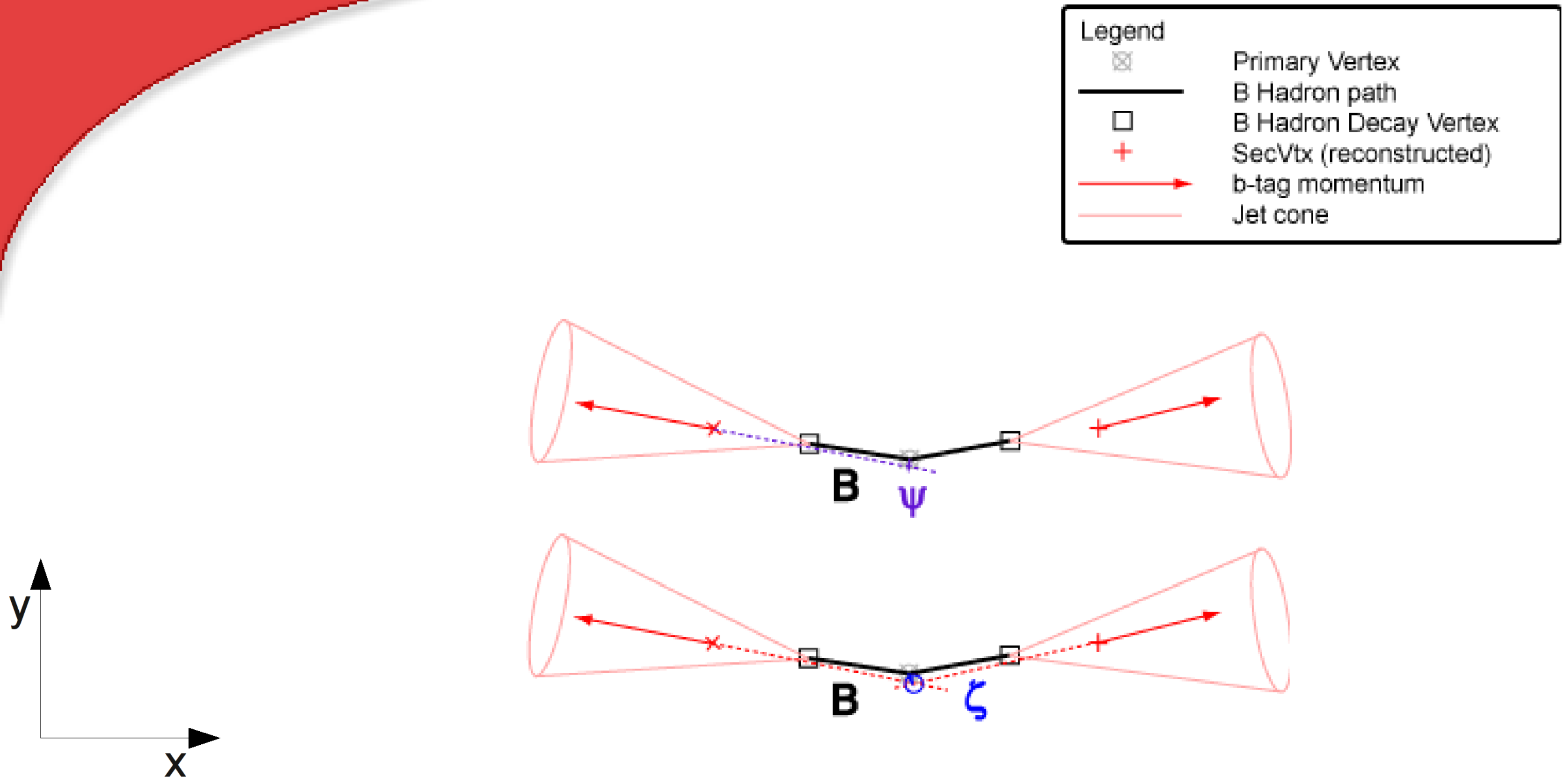
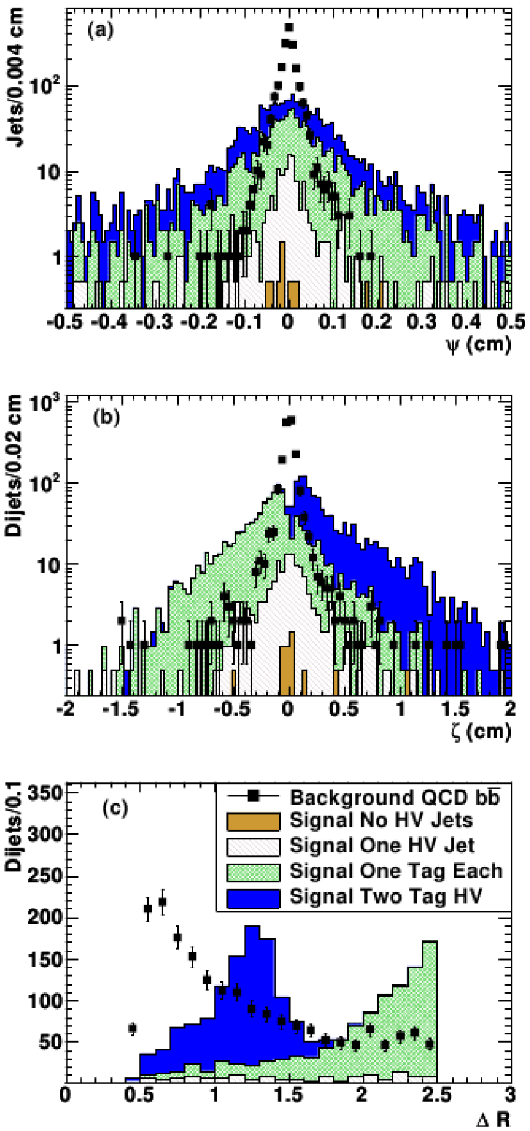


Diagram not to Scale

Here is a typical QCD di-jet event with two b quarks (b & bbar) decaying into two B hadrons. Each has a reconstructed secondary vertex represented by a red cross. Both ψ/ζ are very small for these background events.

Signal MC



- Five signal MC samples generated.
  - h_0 mass : M_{h0} = 130, 170 GeV
  - HV mass : M_{HV} = 20, 40 , 65 GeV
  - HV lifetime : $c\tau$ = 1 cm
  - Reweight lifetimes to study: $c\tau$ = 0.3, 2.5, and 5.0 cm
- Compare the signal MC to QCD $b\bar{b}$ background MC
- ΔR is also a discriminant

ZBB Trigger

- This search is performed using the ZBB Trigger.
- This trigger selects displaced tracks, e.g., from B hadron decay.
- Total integrated luminosity is 3.2 fb^{-1}.

TABLE I: ZBB trigger requirements. One of the two level-2 paths, opposite side (OS) or same side(SS) must be satisfied.

Level-1	at least one central calorimeter tower with $E_T > 5$ GeV;
	at least two tracks: one track with $p_T > 5.48$ GeV/c, one with $p_T > 2.46$ GeV/c
Level-2	veto events with a calorimeter cluster with $E_T > 5$ GeV, $1.1 < \lvert\eta\rvert < 3.6$;
	require at least two clusters $E_T > 5$ GeV, $\lvert\eta\rvert < 1.1$, which have $135 < \Delta\phi < 180$;
	at least two SVT tracks with $p_T > 2$ GeV/c, 160 μm $< \lvert d_0\rvert <$ 1000 μm, $\chi^2 < 12$
(OS)	tracks have $150^\circ < \Delta\phi < 180^\circ$
(SS)	tracks have $2^\circ < \Delta\phi < 30^\circ$
Level-3	at least two $\Delta R = 0.7$ jets with $E_T > 10$ GeV, $\lvert\eta\rvert < 1.1$;
	at least two SVT tracks with $p_T > 2$ GeV/c, $\lvert\eta\rvert < 1.2$, 160 μm $< \lvert d_0\rvert <$ 1000 μm;
	at least two COT tracks with $p_T > 1.5$ GeV/c $\lvert\eta\rvert < 1.2$, 130 μm $< \lvert d_0\rvert <$ 1000 μm,
	track impact parameter significance $S(d_0) > 3$, $\lvert\Delta z\rvert < 5$ cm

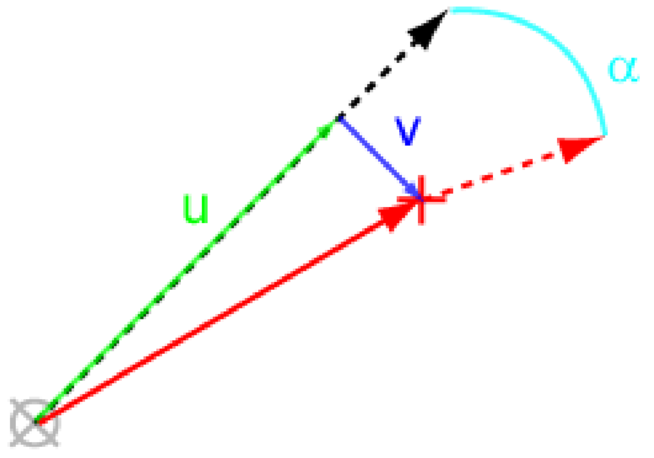
More Event Selection

- We will be looking for events with central b-tagged jets, with a relatively low E_T requirement, i.e. "Signal Region".
  - All jets are required to have:
    - $E_T > 20$ GeV, corrected at Level-5
    - $|\eta|<1.0$
  - Jet multiplicity: $N_{jet} \geq 3$
  - For the dijet system, require that it be in a region that would be populated by signal.
    - $\Delta R < 2.5$
- A "Control Region" is defined which contains events orthogonal to the Signal Region,
  - Two tight central jets ($N_{jet} = 2$)
  - A third jet with Level 5 corrected $E_T < 15$ GeV.
- A new secondary vertex tagger was written because of limitation of SECVTX.
  - The algorithm was modified to increase the efficiency of finding long lived particles
  - The maximum $|d_0|$ cut in the b-tagger is varied to find an optimal cut.

Background Estimate

- We produce a data driven background estimate by looking at orthogonal data samples when possible.
  - Muon calibration data – enriched with b-quarks
  - JET trigger data – light quarks and gluons (light flavor)
  - QCD MC simulation – for c-quarks because there is no dedicated charm trigger.
- Build pdfs of secondary vertices from these data sources which characterize Standard Model secondary vertices.
  - Definition: pdfs are from data, vertex track mass templates are from MC
- Generate pseudoevents where the pdfs are applied to jets in ZBB trigger sample
  - Kinematic information comes from ZBB trigger
  - Secondary vertex information comes from pdfs, i.e., SM background sources
- Calculate: b-tagging probability in ZBB sample and flavor composition of ZBB sample
  - b-tagging probability is the number of events with two b-tags divided by all events; probabilities are calculated in different bins of jet E_T and number of SVT tracks.
  - Flavor composition is performed by generating templates from QCD MC of different quark flavors and fraction fitting the ZBB trigger data.

P.d.f. Diagram



- We use three p.d.f. variables in the plane transverse to the beam line.
  - *u* – the L_{xy} component vector parallel to the jet axis
  - *v* – the L_{xy} component vector perpendicular to the jet axis
  - α – the angle between the secondary vertex momentum and the jet momentum
- Where L_{xy} is the distance from the primary vertex to the secondary vertex in the transverse plane.

Black Dashed Line	Jet Momentum
Red Cross	Secondary Vertex
Red Solid Line	Sec Vertex L_{xy}
Red Dashed Line	Sec Vertex Momentum
Green Line (u)	Parallel component of L_{xy}
Blue Line (v)	Perp. component of L_{xy}
Cyan Arc (α)	Angle b/w the two momenta

Analysis Cuts

- Generate multiple ensembles of pseudoevents; 10,000 “pseudoexperiments.”
- Each is independent and subject to the same analysis cuts.
- For each pseudoexperiment, a integer number of events pass analysis cuts; we take the mean number as the background estimate.
- These cuts optimize S/√B in two searches: high and low HV masses.
  - Top table shows the analysis cuts on the discriminants.
  - Bottom table shows additional cuts that were applied to remove some unexpected background where two secondary vertices are found to be coincident.
  - These originate from decay products from a single b-jet being found in two jet cones. This motivates the mass cut.

Variable	high HV mass		low HV mass	
$\lvert d_0\rvert_{max}$ (cm)	$<$	1.0	$<$	1.0
ΔR_{min}	$>$	0.75		$n.a.$
ΔR_{max}	$<$	2.0	$<$	0.75
$\lvert\psi\rvert$ (both jets) (cm)	$>$	0.11	$>$	0.12
ζ (cm)	$>$	0.8	$>$	0.7
$\lvert\zeta\rvert$ (cm)	$<$ Minimum$(L_{xy\ 1}, L_{xy\ 2})$			

Variable	low HV mass	
ΔS_{2d} (cm)	$>$	0.06
OR		
Σm_{vtx} (GeV/c^2)	$>$	5.0

Search Results

- Expected Signal MC after all cuts
- Background estimate for each HV mass search
- We observe 1 event in the low HV mass search and one different event in the high HV mass search.

Higgs Boson Mass (GeV/c^2)	HV Mass (GeV/c^2)	HV life-time (cm)	Expected Signal MC	Background Estimate	Number Observed
low HV mass search					
130	20	1.0	0.64	0.58	1
170	20	1.0	0.074	0.58	1
high HV mass search					
130	40	1.0	0.26	0.29	1
170	40	1.0	0.38	0.29	1
170	65	1.0	0.14	0.29	1
130	40	0.3	0.24	0.29	1
130	40	2.5	0.10	0.29	1
130	40	5.0	0.043	0.29	1

Systematic Uncertainty

- Systematic Uncertainties on the data
  - Statistics from pdfs
  - Tagging probability systematic
  - Flavor composition systematic
- Systematic Uncertainties on MC
  - Jet Energy Scale (JES)
  - Uncertainty from the trigger
  - Tagging scale factor
  - Parton distribution function
  - Luminosity

Uncertainty	Down (%)	Up (%)
Background estimate - low HV mass search		
Data statistics	± 0.039	
Tag prob. statistics	-7.7	3.4
Flavor composition	-0.5	2.75
Background estimate - high HV mass search		
Data statistics	± 0.046	
Tag prob. statistics	± 3.9	
Flavor composition	-0.5	8.9
Signal MC		
Jet Energy Scale	-15.6% to -6.3%	4.0% to 25.5%
Trigger Unc.	± 8.9	
Tagging scale factor	± 10	
P.d.f.	± 2.5	
Luminosity	± 6	

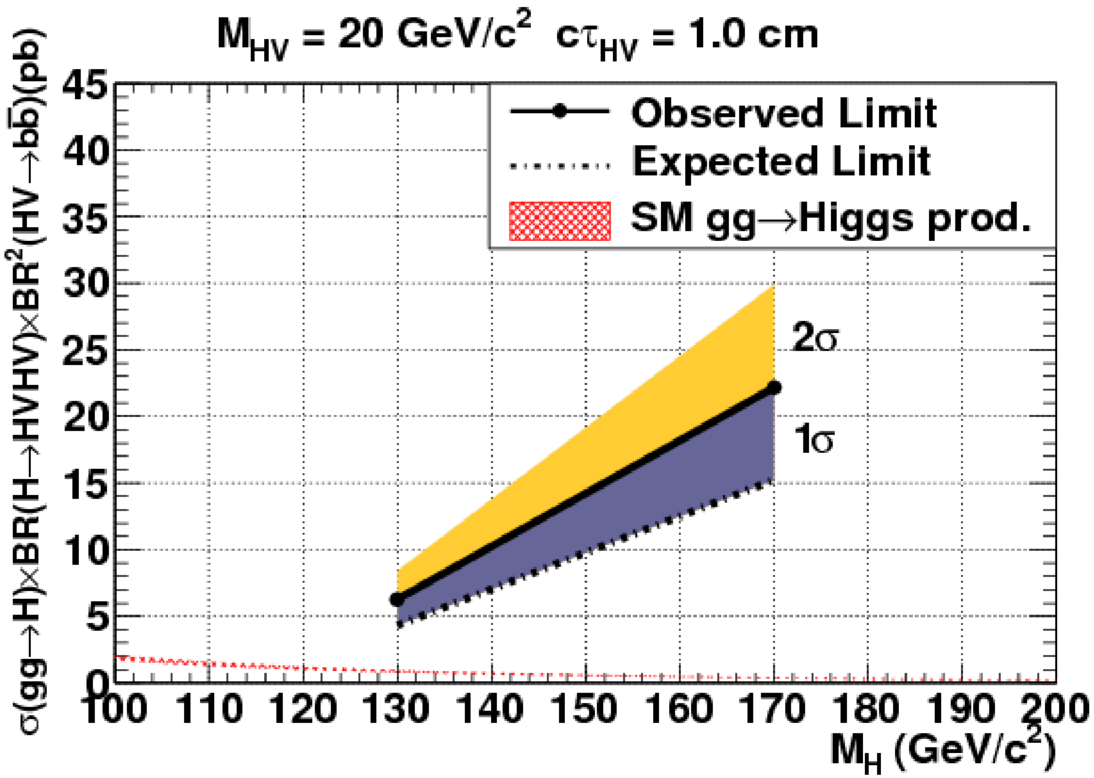
P−values and Limits

Higgs Boson Mass (GeV/c^2)	HV Mass (GeV/c^2)	HV life-time (cm)	p-value
low HV mass search			
130	20	1.0	0.44
170	20	1.0	0.43
high HV mass search			
130	40	1.0	0.27
170	40	1.0	0.26
170	65	1.0	0.26
130	40	0.3	0.27
130	40	2.5	0.27
130	40	5.0	0.27

Higgs Boson Mass (GeV/c^2)	HV Mass (GeV/c^2)	HV life-time (cm)	Obs. Limit (pb)	Expected Limit (pb) -2 σ	-1 σ	median	+1 σ	+2 σ
low HV mass search								
130	20	1.0	6.2	4.3	4.3	4.3	6.2	8.4
170	20	1.0	22.1	15.2	15.2	15.2	22.1	29.9
high HV mass search								
130	40	1.0	15.9	10.5	10.5	10.5	15.9	21.5
170	40	1.0	4.4	2.9	2.9	2.9	4.4	6.0
170	65	1.0	11.7	7.7	7.7	7.7	11.7	15.7
130	40	0.3	17.8	11.7	11.7	11.7	17.8	24.2
130	40	2.5	40.7	26.8	26.8	26.8	40.7	55.1
130	40	5.0	94.3	62.0	62.0	62.0	94.3	127.9

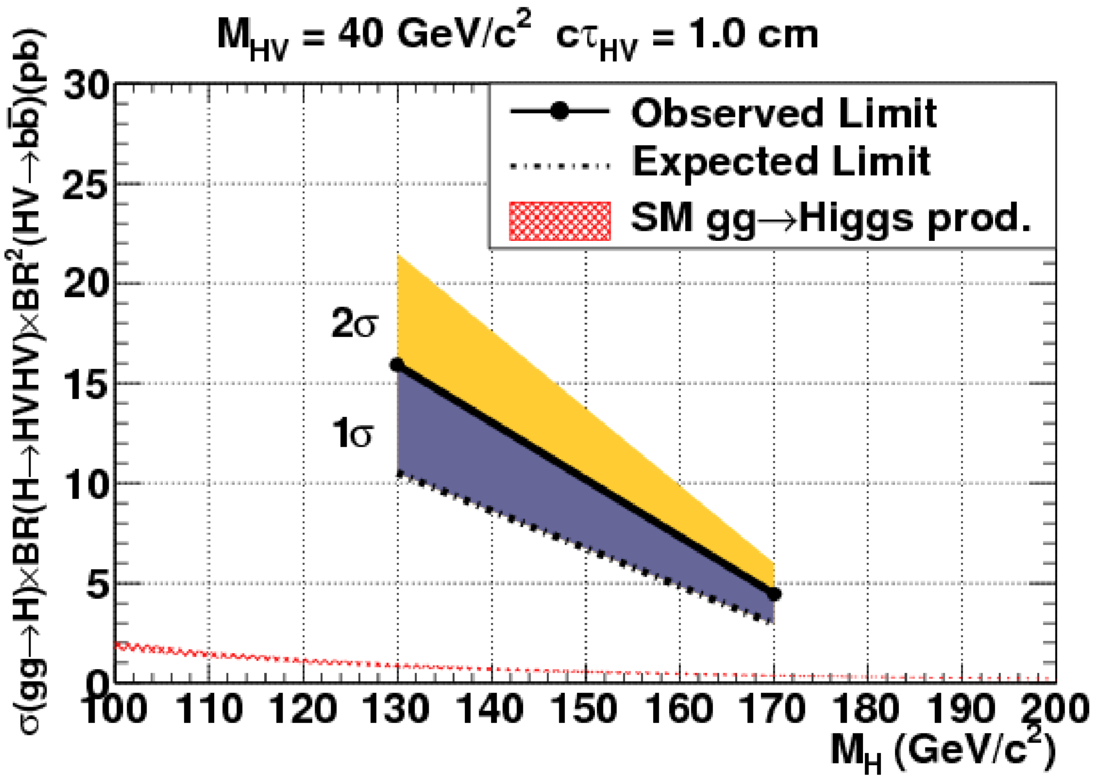
P-values for the null-hypothesis of our search. Limits calculated at 95% confidence level.

Limit Figures



Observed and expected limits at 95% confidence level with 1 and 2 σ bands.
The hashed line is SM Higgs boson production.

Limit Figures



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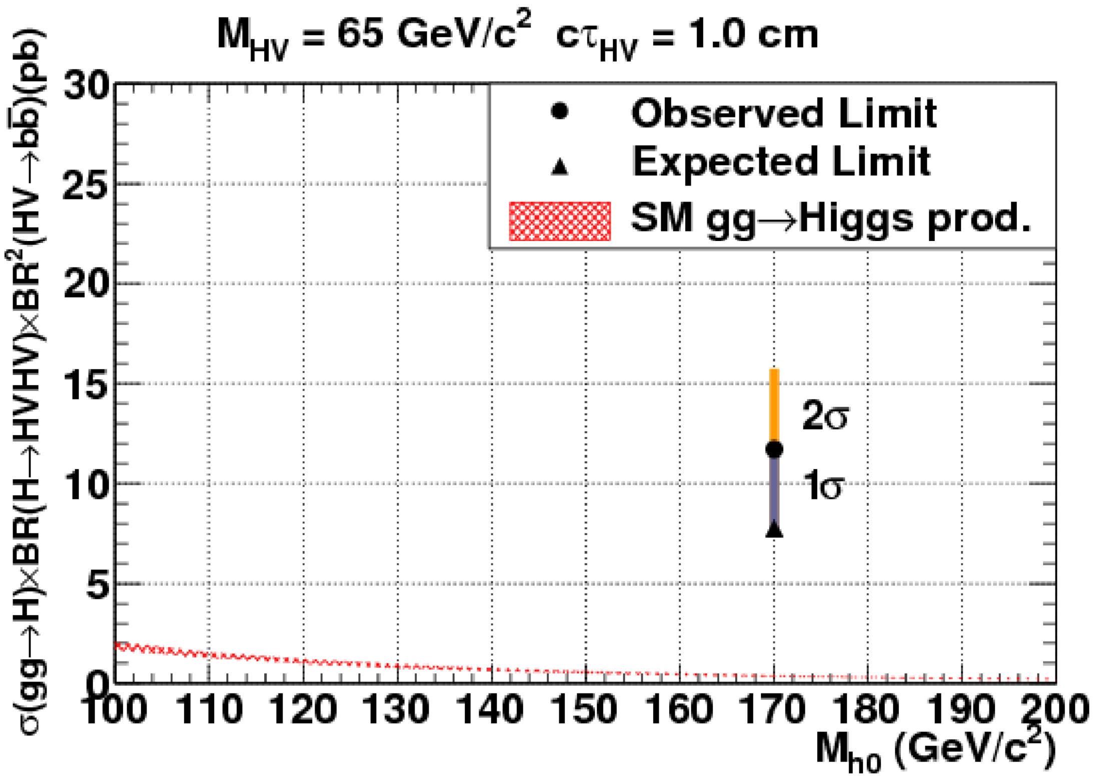

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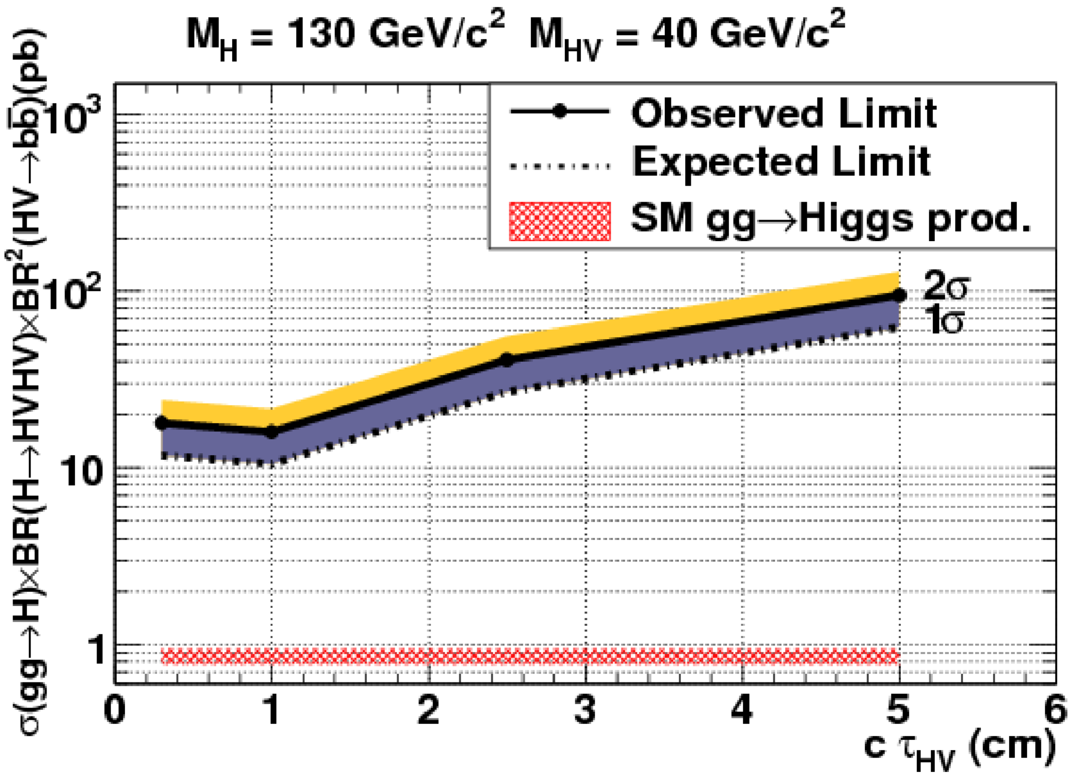
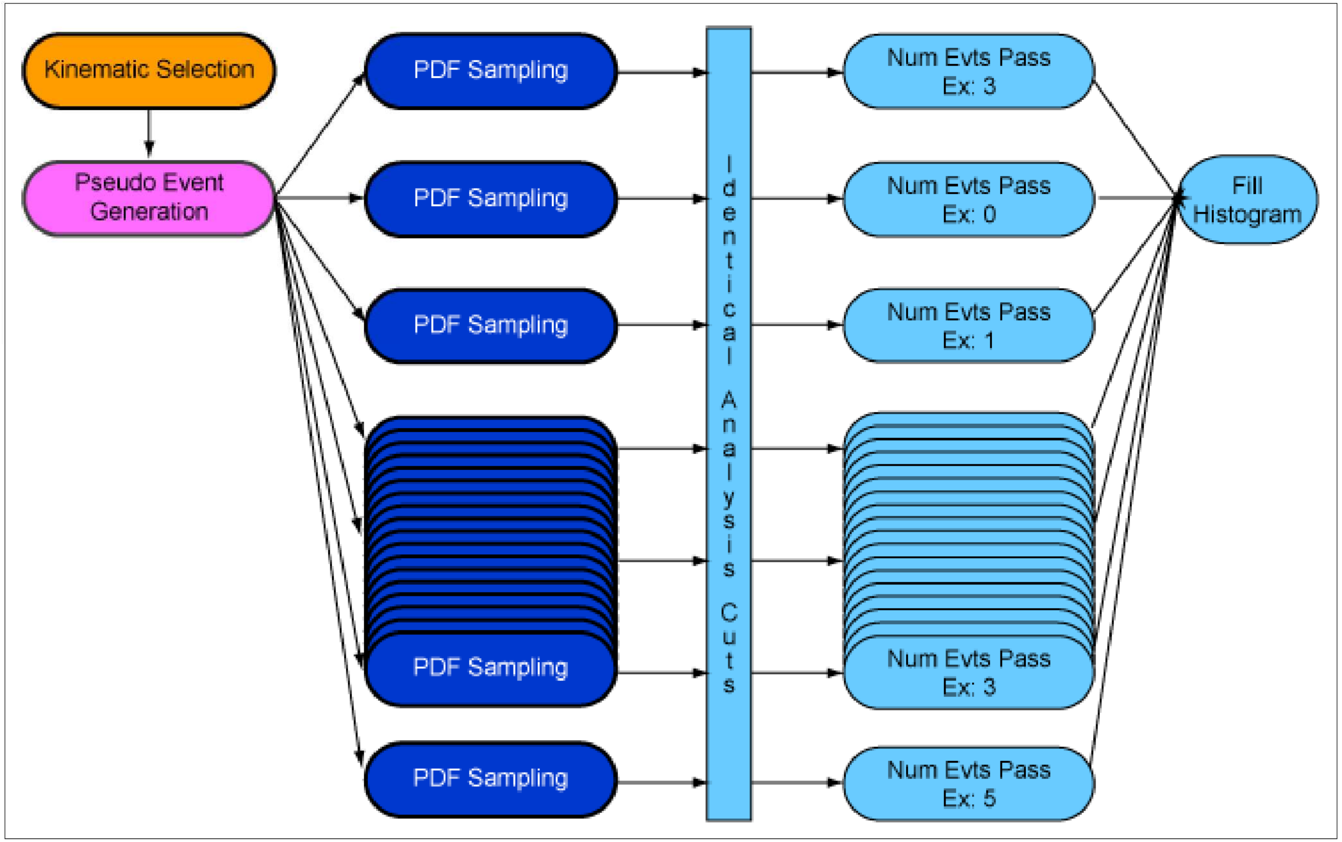


Observed and expected limits at 95% confidence level with 1 and 2 σ bands.
The hashed line is SM Higgs boson production.

Conclusion

- No statistically significant excess is observed about the background. Limits are set on HV production.
- Web site for this analysis:
  - http://www-cdf.fnal.gov/internal/physics/godparents/dispvtx2010/
  - http://www-cdf.fnal.gov/physics/new/hdg/Results_files/results/HV_Dec2010/

Flowchart



The orange and magenta boxes represent the steps selecting an event, and generating a psuedoevent. Now we sample from the PDFs many times (navy). The resulting events are passed through analysis cuts.

The results of these cuts are stored for each "pseudo-experiment," and the resulting number of background events are filled in a single histogram.